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China: Impact of Climate Change to 2030
A Commissioned Research Report

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China: The Impact of Climate Change to 2030

A Commissioned Research Report

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Joint Global Change Research Institute and
Battelle Memorial Institute, Pacific Northwest Division

The National Intelligence Council sponsors workshops and research with nongovernmental experts to gain knowledge and insight and to sharpen debate on critical issues. The views expressed in this report do not reflect official US Government positions.

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Scope Note

Following the publication in 2008 of the National Intelligence Assessment on the National Security Implications of Global Climate Change to 2030, the National Intelligence Council (NIC) embarked on a research effort to explore in greater detail the national security implications of climate change in six countries/regions of the world: India, China, Russia, North Africa, Mexico and the Caribbean, and Southeast Asia and the Pacific Island States. For each country/region we are adopting a three-phase approach.

- In the first phase, contracted research—such as this publication —explores the latest scientific findings on the impact of climate change in the specific region/country.
- In the second phase, a workshop or conference composed of experts from outside the Intelligence Community (IC) will determine if anticipated changes from the effects of climate change will force inter- and intra-state migrations, cause economic hardship, or result in increased social tensions or state instability within the country/region.
- In the final phase, the NIC Long-Range Analysis Unit (LRAU) will lead an IC effort to identify and summarize for the policy community the anticipated impact on US national security.

The Joint Global Change Research Institute (JGCRI) and Battelle, Pacific Northwest Division (Battelle, PNWD), developed this assessment on the climate change impact on China through 2030 under a contract with SCITOR Corporation. The Central Intelligence Agency's Office of the Chief Scientist, serving as the Executive Agent for the DNI, supported and funded the contract.

This assessment identifies and summarizes the latest peer-reviewed research related to the impact of climate change on China, drawing on both the literature summarized in the latest Intergovernmental Panel on Climate Change (IPCC) assessment reports and on other peer-reviewed research literature and relevant reporting. It includes such impact as sea level rise, water availability, agricultural shifts, ecological disruptions and species extinctions, infrastructure at risk from extreme weather events (severity and frequency), and disease patterns. This paper addresses the extent to which regions within China are vulnerable to climate change impact. The targeted time frame is to 2030, although various studies referenced in this report have diverse time frames.

This assessment also identifies (Annex B) deficiencies in climate change data that would enhance the IC understanding of potential impact on China and other countries/regions.

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Executive Summary

China is well known for its size: it has the world's largest population, the third largest land area, the fourth (nominal) or second (purchase power parity) largest economy and is the second largest primary energy producer and consumer and the largest carbon dioxide emitter.[1]

As a major global player in human-caused climate change, China is vulnerable to the adverse impacts of climate change:

- Over the past century (1908 to 2007), the average temperature in China has risen by 1.1 degree Celsius.
- Although no significant trend was observed in nationally averaged precipitation amounts over the past 50 years, a drying trend was observed in the Yellow River Basin and North China Plain.
- Over the past 30 years, the sea level and sea surface temperature have increased 90 millimeters (mm) and 0.9^{o}C, respectively.
- ***China has experienced more extreme events (floods, droughts, storms) in recent years than ever before.*** The extreme weather events have caused direct economic losses of $25 to 37.5 billion in China per year.

One regional climate model projects a country-averaged annual mean temperature increase of 1.3-2.1°C by 2020 (2.3-3.3°C by 2050); another regional climate model projects a 1-1.6°C temperature increment and a 3.3-3.7 percent precipitation increase between 2011 and 2020, depending on the emissions scenario.

By 2030, sea level rise along coastal areas could be 0.01-0.16 meters, increasing the possibility of flooding and intensified storm surges, leading to degradation of wetlands, mangroves, and coral reefs. ***Agricultural growing seasons will lengthen and the risk of extreme heat episodes will increase. Storms may intensify, but warming temperatures are likely to enhance drying in already-dry areas, so both droughts and floods may increase.***

Compared to other countries, China ranks lower in resilience to climate change than Brazil, Turkey, and Mexico, but higher than India. China ranks high in food security, human health, and human resources. ***Projections of resilience show China gaining capacity quickly and outranking Brazil, Turkey, and Mexico by 2020.***

In recent years, the Chinese Government has paid increasing attention to the negative consequences of climate change. In 2007, China laid out its roadmap to battle climate change in *China's National Climate Change Program*, which was followed by a white paper in 2008 titled *China's Actions and Policies on Climate Change*. Both documents reviewed China's past achievements and presented its future plans in the following areas:

[1] Office of Energy Markets and End Use of the Energy Information Administration, "World Carbon Dioxide Emissions from the Consumption and Flaring of Fossil Fuels, 1980-2006," International Energy Annual 2006 Table H.1co2, December 8, 2008, http://www.eia.doe.gov/pub/international/iealf/tableh1co2.xls (accessed January 15, 2009).

- Strengthening government management in vulnerable sectors such as water resources, agriculture, forestry, and coastal regions.
- Building early-warning and monitoring networks.
- Raising public awareness.
- Enhancing R&D investment.
- Employing international resources.

China is thus demonstrating its determination to tackle climate change issues as an important domestic affair. However, some prominent climate impacts have seemingly not caught the government's attention, such as the underrated and underpublicized water crisis, as well as the underdeveloped social protection system. In addition, China must demonstrate an ability to implement its ambitious plans.

The negative consequences of climate change may expose the following sectors to high risk:

- **Water.** ***Scarcity of natural water resources, fast-growing urbanization and industrialization, severe water pollution, cheap water prices, and the adverse impacts of climate change on water sources may lead to a water crisis in China.*** The drought regions in northern China may be prone to social unrest caused by conflicts about water rights and distribution between social groups and between sectors. The expected South-to-North Water Diversion Project may alleviate the water stress of some northern regions, but it will not provide a full solution (and has in any case been delayed).[2] ***The forthcoming water crisis may impact China's social, economic, and political stability to a great extent.***
- **Coastal Regions.** ***Due to their flat and low landscape, China's coastal regions, the engine of China's economic achievement, are highly vulnerable to storm, flood, and sea-level rise.*** The increasing frequency and intensity of extreme weather events such as typhoons has threatened economic development at local, regional, and national levels. China has been actively developing early warning systems and related monitoring systems and improving the design standards of sea dikes and port docks. These efforts may help buffer some risk of natural weather extreme events.
- **Social and Political Uncertainties.** Facing a large unemployed population, China's underdeveloped social protection system is less and less able to protect those who need it. Rising expenses in health care, education and housing have been financial burdens for the average Chinese family. The export-oriented economy is vulnerable to a global financial crisis. The increasing dependence on foreign oil exposes China to an unstable world oil market. ***The adverse impacts of climate change will add extra pressure to existing social and resource (such as energy) stresses.*** Establishing an effective social protection system should be ranked high on the Chinese Government's long to-do list.

[2] E.L. Malone and A.L. Brenkert, "Vulnerability, sensitivity, and coping/adaptive capacity worldwide," *The Distributional Effects of Climate Change: Social and Economic Implications*, M. Ruth and M. Ibarraran, eds., Elsevier Science, Dordrecht (in press).

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Introduction and Background

China is the world's third largest country in terms of land area, after Russia and Canada. Its land sprawls from the plateaus and mountains in the west to the lower lands in the east. The Yellow River (or Huang He) and the Long River (or Chang Jiang) are the two main rivers running from west to east, flowing into the Pacific Ocean.

With soaring economic growth over the past two decades, China has successfully transformed itself into a global economic giant. In 2007, China's GDP reached $3.25 trillion (nominal) and $7.10 trillion (purchasing power parity, PPP), ranked as the fourth and second place in the world, respectively.[i] Meanwhile, China's thriving economy has placed the country as one of the top two carbon emitters for years. In 2006, China finally surpassed the United States and became the largest carbon emitter.[ii]

Mitigation of greenhouse gas emissions (GHG), along with energy conservation, has long been regarded as the key strategy for China to battle climate change. With the increasing number of extreme weather events, China has started to focus on adaptation and adaptive capacity building.

Since 1949, mainland China has been governed by the Chinese Communist Party (CCP). In 1978, CCP undertook an unprecedented economic reform, aiming to transfer China from a Soviet-style central planning economy to a system: "Socialism with Chinese characteristics." In the 30-year-long period of impressive economic growth, private sector and joint-venture companies have dominated China's manufacturing output. Meanwhile, the Chinese Government maintains firm control over such key sectors as banking, telecommunications, and energy.[iii] Media is a mixed story: the government sets boundaries for political coverage but grants the media more freedom to report social news. With 300 million Internet users,[iv] public opinions expressed on the Internet may play a role in directly or indirectly influencing China's social and political progress.

Although widely admired for achieving fast-paced economic growth, the most populous country (1.3 billion by the end of 2007), scores low for some of the economic indicators on a per capita basis. For example, China's GDP per capita ranked 109th (nominal) or 106th (PPP) among 181 countries, according to the World Bank in 2007. The Gini coefficient[3], a key indicator of income equity, reached an alarming .469[v] (UN 2008). In the late 1990s, nearly 30 million workers were unemployed due to the reform of state-owned enterprises. Millions of workers were left in a dire situation and found it difficult to support their families.[vi] The 2008 global financial crisis has hit coastal regions—where the export-oriented economy is dominating—hard.

Given the unbalanced regional economic development between the western and eastern regions of China, an underdeveloped social protection system for the poor, a new annual labor force of 10 million in a nearly saturated job market, as well as spotty terrorist activities led by Islamic extreme groups and the unrest from Tibetan anti-government organizations, social stability is China's top governance priority.

[3] The Gini coefficient is a measure of statistical dispersion most prominently used as a measure of inequality of income distribution or inequality of wealth distribution. It is defined as a ratio with values between 0 and 1. A low Gini coefficient indicates more equal income or wealth distribution, while a high Gini coefficient indicates more unequal distribution.

Since 2005, CCP has advocated "building a harmonious society,"[vii] a political doctrine formally endorsed by the party in 2006. As *The Washington Post* suggests, it is "a move that further signaled a shift in the party's focus from promoting all-out economic growth to solving worsening social tensions."[viii]

In the midst of social and economic development, China has been distressed by its acute energy and environmental pressures. China's economy is mainly fueled by coal, which accounted for 76 percent of its primary energy production and 70 percent of primary energy consumption in 2005. Although coal is its cheapest and largest domestic fossil resource, China faces a daunting challenge for closing its energy gap and mitigating greenhouse gas emissions in a coal-based fast-growing economy. As the second largest oil importer after the United States, China's economy is vulnerable to the unstable international oil market. China has been known for its serious environmental problems as well: Two-thirds of the 338 Chinese cities for which air-quality data are available are considered polluted.[ix] Industrial sources have polluted more than 70 percent of Chinese rivers and lakes, while underground water in 90 percent of Chinese cities is also affected.[x]

The concept of a "harmonious society" has now extended to an environmental dimension – the government has urged society to have a harmonious relationship between nature and economic development.

China is a proven, tough negotiator in international discussions on mandatory mitigation targets. Mr. MA Kai, head of China's powerful National Development and Reform Commission (NDRC), stated clearly at the release of China's first national policy on climate change in 2007, "China will not commit to any quantified emissions reduction targets." Then, Mr. MA added, "…that does not mean [China] will not assume responsibilities in responding to climate change."[xi] Thus, China's current stance may be subject to change.

China has been actively developing national strategies and policies to deal with climate change. After the Earth Summit in 1992, China, being among one of the first participating countries, published *China's Agenda 21* in 1994—a white paper on China's strategies for sustainable development. In 1996, China for the first time addressed sustainable development as its key guideline and strategic goal for national social and economic development. In 2003, China established the National Coordination Committee on Climate Change, headed by the NDRC, and joined by 14 other Chinese Ministries and Administrations.[xii] In 2007, China released *China's National Climate Change Programme* (CNCCP), the first-ever roadmap outlining specific policy objectives, key areas of actions, and mitigation and adaptation policies to address climate change. China also formed the National Leading Group on Climate Change, headed by Premier Wen Jiabao the same year. In 2008, the State Council published an important white paper on *China's Policies and Actions for Addressing Climate Change* (CPAACC), which systematically introduced specific policies and measures on China's adaptive strategies since the release of CNCCP.[xiii]

China's stance on climate change, according to CNCCP, can be summarized as follows: [xiv]

(1) To address climate change within the framework of sustainable development.

(2) To follow the principle of "common but differentiated responsibilities" of the UNFCCC.

(3) To place equal emphasis on both mitigation and adaptation.

(4) To integrate climate change policy with other interrelated policies, and to promote climate change policies in a coordinated manner.

(5) To rely on the advancement and innovation of science and technology.

(6) To participate in international cooperation actively and extensively.

For the first time, the Chinese Government sought to place "equal emphasis on both mitigation and adaptation," although mitigation has long attracted investment and been the key strategy to battle climate change in China. The new stance signaled that China will enhance its investment in R&D, policy and regulatory support, and project development for building adaptive capabilities.

Regarding rising international pressures to reduce its soaring carbon emissions, President Hu, who spoke at the G-8 meeting held in summer 2008 in Japan, advanced three arguments to be considered: "(1) China is a developing country in the process of industrialization and modernization…, (2) China's per capita emissions are relatively low, and are even lower if calculated in accumulative terms..., and (3) as a result of changes in international division of labor and manufacturing relocation, China faces mounting pressure of international transferred emissions."[xv]

China and India, the two largest developing countries, are strong advocates of "common but differentiated responsibilities." The two countries urged developed countries to take the lead in reducing greenhouse gas emissions and called for developing countries to focus on poverty reduction and sustainable development. However, China has received much praise during recent climate forums for its impressive and hard mitigation efforts pushed by the central government,[xvi] while India was criticized for not yet "putting its shoulder to the wheel."[xvii]

China consists of 22 provinces, five autonomous regions (Tibet, Xinjiang Uyghur, Ningxia Hui, Inner Mongolia, and Guangxi Zhuang), four municipalities (Beijing, Tianjin, Shanghai, and Chongqing), and two special administrative regions (Hong Kong and Macau) (see http://en.wikipedia.org/wiki/File:China_administrative.gif#filehistory).

Projected Regional Climate Change

Current Climatology of China[xviii]

China extends from 53° to 18° N and from 73° to 134° E and has a wide range of complex topography (see http://www.askasia.org/images/teachers/media/43.gif) and climates. China's climate varies from tropical to cold temperate and from high mountain to desert. The most productive and populated part of the country is found in the coastal regions fronting the Pacific and the valleys of the three great rivers: Huang He, Chiang Jiang, and Xi Jiang. In addition, the outer territories of China consist of Manchuria in the northeast, Inner Mongolia in the north, Xinjiang Uygur in the west, and Tibet in the southwest. The southern borders with Pakistan, India, and Nepal consist of some of the most mountainous territory in the world.

The climate of central China and Manchuria is dominated by the great seasonal wind reversal called the Asiatic monsoon. From October until April winds tend to blow out from China and the heart of Asia under the influence of the great high-pressure system which develops in Siberia and central Asia at that time. From May until September or October, as the continent of Asia heats up, this area becomes one of low atmospheric pressure and winds are drawn into much of China, both from the Indian Ocean and the Pacific. These warm, moist winds bring most of the

annual rainfall to Manchuria and China proper at that time. Tibet, Xinjiang Uygur, and Inner Mongolia, furthest removed from the influence of the sea, receive much less rain. China proper at that time. Tibet, Xinjiang Uygur, and Inner Mongolia, furthest removed from the influence of the sea, receive much less rain.

North China, including Manchuria, has extremely cold winters of almost Siberian severity; Inner Mongolia and Xinjiang Uygur share in this winter cold. Tibet, a great upland plateau rimmed by some of the highest mountains in the world, has cool summers and very cold winters. In the northwest, Turphan sits in a depression 150m below sea level and is referred to as the "hottest place in China" with maximums of around 47^{o}C.

South and central China have a tropical or subtropical climate with no real winter cold. Eastern China has abundant summer rain while the northern and western regions contain much desert and semi-desert.

The coastal regions occasionally receive very heavy rainfall from typhoons, or tropical cyclones, which intensify in the South China Sea and move northeastward along the coast. The very strong winds associated with these disturbances are most severe in the coastal belt. Typhoons are most frequent from July to October.

South China is partly within the tropics and is the warmest and wettest part of the country in summer. Rainfall is very heavy between May and September along the coast and abundant inland. Winters are mild and frost almost unknown.

Maps showing average annual temperature, precipitation, and vegetation cover are available at http://www.chinamaps.org/china/china-temperature-map.html; http://www.chinamaps.org/china/china-map-of-precipitation.html; http://www.chinamaps.org/china/china-land-cover-map-large-2.html).[xix]

Vast arid and semi-arid desert regions in northwestern China and along the boundary area of China and Mongolia produce dust storms that can occur in any season including in summer and fall. The largest storms mainly occur in spring. These storms affect not only China and Mongolia but also areas downwind including Korea, Japan, and even the Pacific, Hawaii and the west coast of North America. Understanding and quantifying the climatic effect of the aeolian dust, mostly consisting of mineral aerosols, from these storms is important for predicting climate change in China.

China has two of the Earth's major natural dust sources: the Taklamakan Desert in the west China and the Gobi Desert in Mongolia and northwest China.

Estimates of the amount of dust produced annually from China's desert vary greatly. One study (Zhang et al)[xx] derived an annual dust production of 800 megatons (ranging from 500–1100 megatons) from China deserts, which included Taklamakan Desert and Gobi Desert in Inner Mongolia. In another study[xxi] a detailed analysis was conducted on one major dust event (April 2001) and it was found that the total dust production for all particles (diameters less than 36 mm) was about 643 megatons over a ten day period the period. The estimated emissions from this one event are almost equal to the estimated total annual emissions from Zhang et al.

A number of factors influence the annual production of dust, including meteorological conditions, climatic cycles such as El Niño–Southern Oscillation and North Atlantic Oscillation, and changes in land-use and land-cover, including the increasing desertification noted in some

regions of China. Using a dust emission model, the relative contribution to the annual dust emissions from Mongolia, Taklimakan and Badain Jaran were 29 percent, 21 percent and 22 percent of the Asian dust, respectively.[xxii] (For a map of global worldwide emissions of dust, see T.D. Jickells, R.A. Duce, K.A. Hunter, et al. "Global Iron Connections Between Desert Dust, Ocean Biogeochemistry, and Climate." *Science* 308 (April 1, 2005): 67)

The direct and indirect atmospheric radiative forcing by dust has implications for global climate change and presently is one of the largest unknowns in climate models. Development of a better parameterization of the effects of dust on climate change is important to building a better climate model.

China has about 50,000 rivers located mostly in the southern and eastern areas of the country. More than 1,500 of these rivers lie in basins of at least 1,000 km^2. Major rivers include theYangtze, Yellow, Soughua, Liaohe, Haihe, Huaihe and Pearl Rivers. These river basins, inhabited by 50 percent of China's population and contributing to over 2/3 of China's agricultural and industrial production, frequently experience significant flooding. The climate in these regions is dominated by the East Asia monsoon in the summer and by continental air currents in winter.

China's history is filled with reports of the frequent flooding of major rivers. Natural disasters such as floods destroy (on average) a reported 4,182,000 houses per year with some four million people per year needing to be urgently resettled or transferred from their homes.[xxiii] Because of the high population density in the river basins, floods in China generally affect large numbers of victims. The Yangtze Basin is home to 400 million people, with an average density of 214 people/km^2, making it the most densely populated basin in the world. The Yangtze River floods in China in 1991 and 1998 affected a total of 210 million and 238 million people respectively. The latter disaster forced China to request international aid for the first time.

Climate Observations

China's Assessment Report on Climate Change[xxiv] includes an evaluation of mean temperature, precipitation, and other climate data from 740 stations across Mainland China. Annual mean surface air temperature in Mainland China as a whole rose by about 1.1 ^{o}C for the last 50 years, with a warming rate of about 0.22 ^{o}C per 10 years. This rate of warming is significantly higher than the 100-year linear warming trend (1906-2005) of 0.74 ^{o}C observed at the global scale.[xxv] The largest warming occurred in winter and spring and in Northeast China, North China and Northwest China. A cooling trend was observed in Southwest China, as reported in earlier studies. Summer mean temperature in the middle and lower reaches of the Yangtze River also decreased in the last 50 years.

No significant trend was observed in nationally averaged precipitation amounts over the past 50 years. However, a drying trend was observed in the Yellow River Basin and North China Plain, with the largest drop in precipitation amounts occurring in Shandong Province. A small increase in annual precipitation was observed in the Yangtze River Basin, resulting primarily from increased summer rainfall.

Since 1956, the country-averaged pan-evaporation rate (a measure that corrects for temperature, humidity, solar radiation etc.) has decreased a small amount, although this could be due to a reduction in solar radiation at the surface. In parts of the North China Plain, annual sunshine duration in the recent years is almost 500 hours fewer than that of 50 years ago. Some studies

have suggested that there are changes in the frequency and magnitude of extreme weather and climate events over the past 50 years;[xxvi] however, this is not universally accepted.

There has been a significant increase in aerosol pollution throughout China, especially in the urban areas. Menon[xxvii] has suggested that the observed trend toward increased summer floods in south China and drought in north China, thought to be the largest change in precipitation trends since 950 A.D.,[xxviii] may have an alternative explanation: human-made absorbing aerosols in remote populous industrial regions that alter the regional atmospheric circulation and contribute to regional climate change. Menon's research also suggests that the spatially varying atmospheric heating caused by black carbon (BC) alters the Asian summer monsoonal circulation causing the change in precipitation patterns over China.

Regions at higher latitudes are experiencing a faster rate of warming than the more temperate regions. Mongolia, particularly around Lake Hovsgol, has been warming more than twice as fast as the global average. Winter temperatures in Mongolia have increased a staggering 3.6°C on average during the past 60 years.[xxix]

Climate Predictions (Modeling)

Although Global Circulation (or Climate) Models (GCMs) can be used to infer climate changes in specific regions, it is far preferable to develop models that have a high resolution sufficient to resolve local and regional scale changes. There are many challenges in reliably simulating and attributing observed temperature changes at regional and local scales. At these scales, natural climate variability can be relatively larger, making it harder to distinguish long-term changes expected due to external forcings.

The procedure of estimating the response at local scales based on results predicted at larger scales is known as "downscaling." The two main methods for deriving information about the local climate are (1) dynamical downscaling (also referred to as "nested modeling" using "regional climate models" or "limited area models") and (2) statistical downscaling (also referred to as "empirical" or "statistical-empirical" downscaling).[xxx] Chemical composition models include the emission of gases and particles as inputs and simulate their chemical interactions; global transport by the winds; and removal by rain, snow, and deposition to the earth's surface.

Downscaled regional- scale climate models rely on global models to provide boundary conditions and the radiative effect of well-mixed greenhouse gases for the region to be modeled. There are three primary approaches to numerical downscaling: (1) limited-area models, (2) stretched-grid models, and (3) uniformly high resolution atmospheric GCMs (AGCMs) or coupled atmosphere-ocean (-sea ice) GCMs (AOGCMs).

The magnitudes and patterns of the projected rainfall changes differ significantly among models, probably due to their coarse resolution. The Atlantic and Pacific Oceans are strongly influenced by natural variability occurring on decadal scales, but the Indian Ocean appears to be exhibiting a steady warming. Natural variability (from El Niño- Southern Oscillation [ENSO], for example) in ocean-atmosphere dynamics can lead to important differences in regional rates of surface-ocean warming that affect the atmospheric circulation and hence warming over land surfaces.

Including sulfate aerosols in the models damps the regional climate sensitivity, but greenhouse warming still dominates the changes. Models that include emissions of short-lived radiatively active gases and particles suggest that future climate changes could significantly increase

maximum ozone levels in already polluted regions. Projected growth of emissions of radiatively active gases and particles in the models suggest that they may significantly influence the climate, even out to year 2100.[xxxi] Atmospheric brown clouds, plumes of polluted air moving from the Asian continent out over the Pacific Ocean, may cause precipitation to increase over the Indian Ocean in winter and decrease in the surrounding Indonesia region and the western Pacific Ocean, causing a reduction in summer monsoon precipitation in South and East Asia.

Stabilization emissions scenarios assume future emissions based on an internally consistent set of assumptions about driving forces (such as population, socioeconomic development, and technological change) and their key relationships. These emissions are constrained so that the resulting atmospheric concentrations of the substance level off at a predetermined value in the future. For example, if one assumes the global CO_2 concentrations are stabilized at 450 parts per million (ppm) (the current value is about 380 ppm), the climate models can be tuned to produce this result. The tuned model predictions for regional climate changes can be used to assess specific impacts at this stabilization level. A more detailed discussion of the ability of the models to project regional climate changes can be found in Appendix A.

Climate Projections of Future Temperature and Precipitation

Climate changes in temperature and precipitation over China have been projected based on a regional climate model developed by the National Climate Center/China Meteorological Administration (NCC/CMA) and the Institute of Atmospheric Physics/Chinese Academy of Sciences (IAP/CAS).[xxxii]

Gao et al.[xxxiii] worked with a regional climate model (named RegCM/China), a modified version of the NCAR/RegCM2 model, to make climate projections up to the year 2100. The model results indicate that a significant warming will occur in the 21st century in China, with the largest warming occurring in winter and in the northern portions of China. Under varied emission scenarios of greenhouse gases, the country-averaged annual mean temperature is projected to increase by 1.3-2.1°C by 2020, 2.3-3.3°C by 2050, and 3.9-6.0°C by 2100. The model also projected a 10 percent-12 percent increase in annual precipitation in China by the year 2100, with the increases particularly evident in Northeast China, Northwest China and the Tibetan Plateau. Central China was projected to undergo a drying trend. The model indicated that anthropogenic climate change probably will lead to a weaker winter monsoon and a stronger summer monsoon across East Asia.

Yinlong et al.[xxxiv] worked with PRECIS, (Providing Regional Climates for Impacts Studies), a regional climate model, to obtain high-resolution projections of future climate over China. PRECIS was used to analyze the climate change in the 21st century over China under the A2 and B2 GHGs emissions assumptions constructed in the 2000 *Special Report on Emissions Scenarios* (SRES).[xxxv] PRECIS is a Regional Climate Model (RCM) developed at the UK Met Office Hadley Centre for Climate Prediction and Research with a high horizontal resolution of 50 km-50 km and 19 vertical layers. The model is capable of running at a resolution of 1.875^o in longitude and 1.25^o in latitude.

The model projected changes of surface air temperature and precipitation for three time-slices of the 21st century. By the third time slice, 2071-2100, the temperatures in Northeast China, North China, and Northwest China are projected to increase, while the precipitation amounts are projected to decrease under the SRES B2 scenario. The climate would become warmer and drier over these three regions in the northern part of China; and the precipitation over Central China,

Table 1 Average changes of surface air temperature and precipitation under SRES A2 and B2 scenarios over China from PRECIS simulation relative to baseline (1961–1990), plus corresponding CO_2 concentrations

Time-slice	A2			B2		
	Temperature increment /℃	Precipitation increase /%	CO_2 / (mL/m³)	Temperature increment /℃	Precipitation increase /%	CO_2 / (mL/m³)
2011–2020	1.00	3.3	440	1.16	3.7	429
2041–2050	2.11	7.0	559	2.20	7.0	492
2071–2080	3.89	12.9	721	3.20	10.2	561

Table 2 2071–2100 average changes of mean temperature and precipitation under SRES B2 scenario over seven regions from PRECIS relative to 1961–1990

Regions	Temperature change / ℃					Precipitation change / %				
	Annual	Spring	Summer	Autumn	Winter	Annual	Spring	Summer	Autumn	Winter
Northeast China	3.8	3.1	4.7	3.6	3.9	4	2	1	0	43
North China	3.5	2.9	4.1	3.2	3.8	14	28	2	9	63
Central China	3.0	2.6	3.5	2.9	3.0	11	17	8	4	2
East China	2.7	2.4	2.9	3.0	2.8	9	12	11	−8	2
South China	2.8	3.1	3.0	2.4	2.9	8	13	15	2	−36
Southwest China	2.9	2.6	3.1	2.7	3.1	9	8	7	6	8
Northwest China	3.7	3.0	4.2	3.8	3.7	13	22	4	−2	38
Whole China	3.3	2.9	3.8	3.3	3.5	10	13	6	3	9

East China, and South China would increase largely in summer (not as much in winter); the precipitation in South China in winter would obviously decrease. This means that both the flooding in summer and drought in winter would be enhanced over these three regions in the southern part of China.

Tables 1 and 2 show the results of the analysis. The PRECIS model runs project that average temperature increments at the end of the 21st century over China will be over 3^{o}C, while the percentage of precipitation is projected to increase by 10 percent under SRES A2 and B2 scenarios. The ratio of maximum/minimum surface air temperature during the 2080s under the B2 scenario is projected to increase; changes in extreme events are discussed below.

Projections of Sea Level Changes

A significant fraction of sea level rise is due to thermal expansion of a warmed ocean (as much as 0.3 to 0.8 meters over the last century, according to the Intergovernmental Panel on Climate Change (IPCC)[xxxvi]). Geographic patterns of sea level rise are due mainly to changes in the distribution of heat and salinity in the ocean, resulting in changes in ocean circulation. Precise satellite measurements since 1993 show that the largest sea level rise since 1992 has taken place in the western Pacific and eastern Indian Oceans. There is a large interannual variability in sea level rise associated with patterns of coupled ocean-atmosphere variability, including El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO).

Much of China's coastline is vulnerable to sea level rise. Storm surges, droughts, and other extreme climate events are the main cause of coastal disasters. The Yellow River Delta, the Yangtze River Delta, and the Pearl River Delta are the most vulnerable coastal regions in China. By 2030, the sea levels along China's coastal areas could rise by 0.01-.16 meters,[xxxvii] increasing the possibility of flooding and intensified storm surges. These disasters could increase coastal erosion, degrade coastal ecosystems such as wetlands, mangroves, and coral reefs, and exacerbate saltwater intrusion. In particular, sea level rise would cause significant degradation of wetland, and submergence/erosion of tidal flat land in the Yangtze River Delta. The South China region is also especially susceptible to sea level rise, estimated to be between 0.60-0.74 meters by 2100. This would adversely affect low-lying and damp areas in the Pearl River Delta more than other places. In this case, the border lines of mangrove areas are likely to move northward and the scope of coral bleaching is likely to expand.

Projections of Changes in Agricultural Growing Seasons

The following describes a simulation of the present and future climate using the Regional Integrated Environment Modeling System (RIEMS) and the SRES A2 emissions scenario:[xxxviii]

- The simulated climatic belts, climatic seasons, and Yellow River ice phenology in China are compared between the present climate during 1975–1984 and the future climate during 2035–2044.[xxxix] Compared to 1975-1984, most of the climatic belts in China will shift northward in 2035-2044, by a maximum of 1.5-2° of latitude. The southern boundary of the Northern Sub-tropical Belt (NSB) will shift northward significantly, in spite of the little change in its northern boundary. The entire Southern Sub-tropical Belt (SSB) and the Middle Sub-tropical Belt (MSB), as well as the northern boundary of the Warm Extra-tropical Belt (WEB), will also shift northward by 1-2°of latitude. The starting dates of spring and summer will mostly advance, opposite to the delays in the starting dates of autumn and winter. As a whole, the summer in China will grow longer by 26.1 days, while spring, autumn, and winter will become shorter by 6.8, 7.9, and 11.4 days, respectively. In the upper reach of the Yellow River (URYR), the date for enduring sub-zero temperatures will be delayed by eight days and the date for enduring above-zero temperatures will advance by five days. In the lower reach of the river, the date for enduring sub-zero temperatures will be delayed by four days and the date for enduring above-zero temperatures will advance by four days.

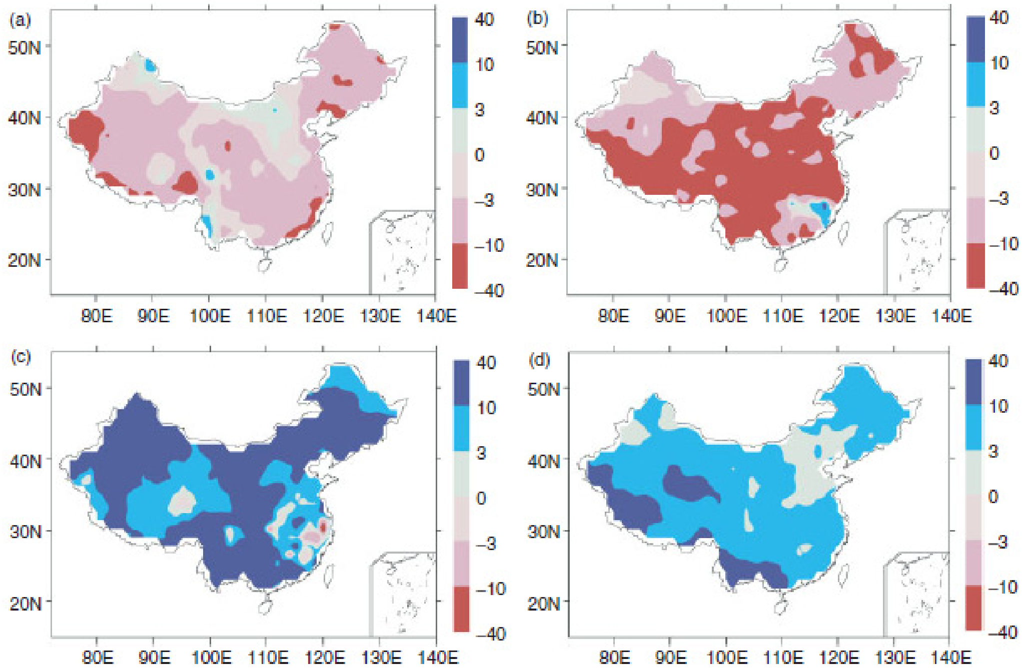


Figure 1. Differences in the starting dates of spring (a), summer (b), autumn (c), and winter (d), between 1975-1984 and 2035-2044. Positive (negative) values represent postponed (advanced) days. Units are in days.

Figure 1 (above) shows the changes in the starting dates of various seasons from 1975-1984 to 2035-2044 when the CO_2 concentration increases by 0.77 times that of the former period. In the spring (a), the starting dates change little in part of southwestern and northwestern China and central-western inner Mongolia, but they are moved forward in the rest of China by more than 10 days in part of Xinjiang and between three and 10 days in a large part of the country including the northeastern and western and central-southeastern areas of China. The biggest advance in the starting dates of seasons occurs in summer (b). Except for part of Fujian province in the southeast, the starting dates of summer move forward by more than three days in most of China. In a large portion of the country, the summer season advances by more than 10 days. Delays in the starting dates of seasons are most pronounced in autumn (c). These delays are generally more than three days, except in part of southeastern China. In northwestern, southern-southwestern China, and central-northern China, the starting dates of autumn are delayed by more than 10 days. The starting dates of winter are postponed by more than three days in a major portion of the country (d). In parts of western and southwestern China, the delays are more than 10 days.

It has been suggested that absorbing aerosols may have masked up to 50 percent of the surface warming in South Asia from the global increase in greenhouse gases. In cases where aerosols act to suppress rainfall (the second aerosol indirect effect), drier conditions tend to induce more dust and smoke due to the burning of drier vegetation, affecting both regional and global hydrological cycles and agricultural production.

Changes in the Frequency or Strength of Extreme Climatic Events

Extremes are the infrequent events at the high and low end of the range of values of a particular variable. The probability of occurrence of values in this range is called a probability distribution function (PDF) that for some variables is shaped similarly to a "Normal" or "Gaussian" curve (the familiar bell-shaped curve).

People affected by an extreme weather event wonder whether climate changes due to human influences are responsible. It is difficult to attribute any individual event to a change in the climate. In most regions, instrumental records of variability typically extend only over about 150 years, so there is limited information to characterize how extreme rare climatic events could be. Further, several factors usually need to combine to produce an extreme event, so linking a particular extreme event to a single, specific cause is problematic. In some cases, it may be possible to estimate the anthropogenic contribution to such changes in the probability of occurrence of extremes.

As the climate changes and sea surface temperatures (SSTs) continue to increase, the conditions that cause tropical storms to form are no longer the same. Higher SSTs are generally accompanied by increased water vapor in the lower troposphere; thus, the moist static energy that fuels convection and thunderstorms is also increased. Hurricanes and typhoons currently form from pre-existing disturbances only where SSTs exceed about 26°C; so, as SSTs have increased, the areas over which such storms can form are potentially expanded. However, many other environmental factors also influence the generation and tracks of disturbances.

The 2007 IPCC assessment concluded that there was a risk of increased temperature extremes, with more extreme heat episodes in a future climate in China. This result has been confirmed and expanded in more recent studies. Future increases in temperature extremes are projected to follow increases in mean temperature over most of the world except where surface properties (e.g., snow cover or soil moisture) change. There is still much debate over whether there is likely to be an increase in tropical cyclone intensity.

Changes in tropical storm and hurricane frequency and intensity are often masked by large natural variability. The El Niño-Southern Oscillation greatly affects the location and activity of tropical storms around the world. Globally, estimates of the potential destructiveness of hurricanes show a substantial upward trend since the mid-1970s, with a trend toward longer storm duration and greater storm intensity, and the activity is strongly correlated with tropical SSTs. One study[xl] found a large increase in numbers and proportion of hurricanes reaching categories 4 and 5 globally since 1970, even as the total number of cyclones and cyclone days decreased slightly in most basins. The largest increase is in the North Pacific, Indian and Southwest Pacific Oceans.

The geography and climatology of China enables the frequent occurrence of extreme events. Summer storms move eastward along the river systems, dumping large amounts of rainfall that can cause severe flooding. As a harbinger of the projected intensification of extreme events in southern and eastern China, Chongqing and Sichuan in the upper Yangtze Basin generally experience a once-every-100-years drought, but was subject to rare flooding in 2007.[xli]

Half of the country's land area is arid or semiarid. Water shortages in northern China over the past three decades have been severe and led to the ongoing construction of the South-North Water Diversion Project, a gigantic project that will divert water from three points of the

Yangtze River basin to the north. Global warming is likely to enhance such drying. China's agricultural output could be reduced by 5-10 percent by 2030, adding stress to a country that has 20 percent of the world's population and only 7 percent of the arable land. Major ecosystem impacts can be expected with the loss of tundra and mountain forests and the intensification of wildfires.

Gao[xlii] recently studied the possible changes of extreme events due to climate change (in a 2x CO_2 scenario) over East Asia, with a focus on the China region as simulated by a regional climate model (RegCM2). His results show a measurable increase in both daily maximum and daily minimum temperatures. The overall diurnal temperature range decreased. The number of days with extreme heat increased, while the number of extreme cold decreased. There was an increase in the number of rainy days and heavy rain days over some sub-regions of China. There was also a change in the frequency of tropical storms affecting the coastlines.

Application of the PRECIS regional model[xliii] to study extreme events showed that the occurrence frequency of extremely high-temperature and extreme precipitation events is expected to increase, while extremely low temperature events are projected to decrease. Drought with high temperature events may become more common in the northern part of China, while flooding in summer in the part of China is expected to increase. The models that have been applied to analyze extreme events in China show some differences, but overall they indicate a general trend of an increasing frequency of daily high temperature extremes, a decrease in the frequency of daily minimum temperature extremes, an increase in both the intensity of precipitation events and the frequency of extreme precipitation events, and an increase in the occurrence of droughts or dry spells. The biggest problem in performing analyses of extreme events for most of the globe is a lack of access to high-quality, long-term climate data with the appropriate time resolution.

China is located in the East Asian monsoon region, where arid and semiarid climate dominates in the northern parts of the country. In this region, the strength of monsoon circulation can cause not only drought/flood and cold/warm events, but also windy conditions and air pollution. Some of the early records of dust storm activity in the world are recorded in ancient Chinese literature referring to dust falls in northern China as ''yellow wind'' or ''black wind,'' as well as ''dust rain' or ''dust fog.'' Dust storms usually occur in the spring and early summer.

Dust storm frequency in the region has increased in the past decade. Although increasing desertification has likely contributed to the increases in dust storms, the increase over the past three years is more logically explained by changes in weather and climate than desertification because the land area affected by desertification changes relatively little over a few years.

China is subject to extensive damage from flooding of its river basins. The Yangtze River flood of 1998 in China submerged more than 21 million hectares of farmland, an area about seven times the size of Belgium. The flood produced an estimated 238 million victims and the cleanup cost was an estimated $30 billion. Clearly, increasing flooding of the river valleys due to climate change will have a significant impact on the country.

Impacts of Climate Change on Natural Ecosystems

Clearly a wide range of environmental observations support the fact that rapid climate change is under way in China.

Since the 1960s, forest cover on Mount Qilian has decreased by 16.5 percent, and its forest belt moved up 400 meters. In Sichuan Province, grass production and quality have decreased. In southwest China, the Sanjiang (Three-River) Plain, and Qinghai Province wetlands have shrunk and their functions declined. Since the 1950s, mountain disasters in Southwest China are more frequent and the losses they have caused have increased. Climate change has raised the potential for disease incidence and transmission, particularly of vector-borne infectious diseases.[xliv]

China's natural systems have witnessed evident impacts of climate change on water resources, sea level rise, forestry, permafrost and glaciers, and deserts.

Water Resources

Besides human development, climate change has been revealed as a key factor in the changes of water resources in China.[xlv] Drought has hit wider areas in northern China and flooding has increased in southern China. Instability in agricultural production has been rising since the 1980s. As plants bud and flower earlier, they are more subject to crop damage from spring frost, which has increased. Also over the past two decades, optimum areas for growing winter wheat in Northeast China have moved northward and extended westward. Production of certain varieties of maize that have a relatively long growth period and high yield have increased overall productivity.

Since the 1950s,[xlvi] water runoffs to six large rivers in China have all been decreasing, with the largest decrease along the Haihe River. Some rivers in northern China face intermittent flow. Large flooding events occurred along the Yangtze, Pearl, Songhua, Huaihe, and Yellow Rivers as well as the Taihu Lake in the 1990s, resulting in increasingly heavy losses. Climate change and sea level rise have already affected China's coastal areas, where the economic losses from storm surges, flooding, heavy rains, drought and other serious climatic events are significant. The Yellow River Delta, Yangtze River Delta, and Pearl River Delta are more vulnerable to storm surge, coastal flooding, shoreline erosion, and losses of wetlands than other coastal places.

Due to the decrease in annual mean runoff, the Ningxia Hui Autonomous Region and the Gansu Province, two neighboring arid provinces in northwestern China, are in danger of facing serious water shortages in the next 50 to 100 years. The Inner Mongolia Autonomous Region and the Xinjiang Autonomous Region, two adjacent provinces of the Ningxia Hui Autonomous Region, may also experience an increasing gap between water supply and demand during the same period. Meanwhile, Hubei and Hunan provinces, two bordering provinces located in the Yangtze River, will face more flooding in the near future.[xlvii]

Sea Level Rise

Over the past 30 years, along the Chinese coast, the sea level and sea surface temperature have increased by 90 millimeters (mm) and 0.9°C, respectively.[xlviii] Sea level rise has not only resulted in seawater intrusion, soil salinization and coastal erosion, but also threatened coastal and marine ecosystems such as mangrove swamps and coral reefs. The rising sea temperature has also degraded marine fishing resources.[xlix]

Liu et al.[l] report that since the 1950s the rates of sea level rise along China's coastline have been between 1.4-3.2 mm per year; marine ice condition on the surface of Bohai Sea and Yellow Sea has decreased; glacier areas in Northwest China have decreased by 21 percent over the past 50 years; the permafrost in Tibet has gotten thinner by up to 4-5 meters; the water levels of some high plateau inland lakes have risen; and grassland production in Sichuan, Qinghai, and southern

Gansu Provinces have decreased. In recent years, coral bleaching has been observed in the coastal of Hainan and Guangxi Provinces.

Forest

The observed impacts of climate change on forestry and other natural ecosystems may be reflected by the northward shift of the northern boundaries of eastern subtropical and temperature zones, the upward move of vertical spectrum of forest belts, increasing frequency of plant diseases and insect pests (such as the American white moth and the pinewood nematode[li]), and increasing forest fires.[lii]

However, as many studies reveal, climate change may bring some positive impacts on China's forestry productivity and output.[liii,liv,lv] Data show that the growing season has been extended by 1.4 to 3.6 days per year in the northern regions and by 1.4 day per year across the country between 1982 and 1993.[lvi] According to a Chinese study published in 2007, net primary productivity grew by 11.5 percent between 1982 and 1999 due to climate change.[lvii]

Permafrost and Glaciers

The Qinghai-Tibet Plateau has the most extensive high-altitude permafrost on earth—one of the most sensitive regions to climate change.[lviii] The Plateau, taking up 25 percent of China's land area, is sometimes called the "water tower of Asia."[lix]

The more pronounced temperature changes in the western and northern parts of China may lead to shrinking permafrost and reduced glacier areas in the Qinghai-Tibet Plateau. The permafrost thickness there decreased a maximum of 4-5 meters, and the glacier areas in northwestern China decreased by 21 percent in the past 50 years.[lx] It is estimated that by 2050 glacier areas in western China will decrease by 27.7 percent, and the spatial distribution of permafrost will face significant change in the Qinghai-Tibet Plateau.[lxi]

Higher average temperatures in summer are thawing permafrost in Mongolia as well and disturbing the soil structure around the shallow tree roots. Scientists working in Mongolia have noted that the mountains are losing their snowcaps, and the glaciers on the northern shore are shrinking.

In the past decade, Mongolia has experienced four of the worst drought years on record. And during the same period, intense storms have grown more frequent, according to a recent IPCC Assessment Report on the impacts of climate change.[lxii] As permafrost retreats deeper or disappears, the ground becomes a giant sponge that removes water away from plant roots. As the taiga forest grows thinner and with the loss of the insulating tree cover, the soil warming accelerates. The drying soil and dying vegetation create a flashpoint, raising the risk of wildfires in an area without firefighting equipment or teams. Wildfires are growing more frequent and fiercer. If the topsoil eroding into Hovsgol's tributaries spurs algal growth in the lake, it could ruin the region's best source of drinking water.

A study of glaciers in the Himalayas show that they are now receding at an average rate of 10-15 meters per year.[lxiii] These glaciers collect water during the monsoon season and release it during the dry season, providing irrigation water for crops. If the rate of glacial melt increases, flooding is likely to occur in the river valleys fed by the glaciers. Later, as the river flows decrease to below previous rates, many people may be left without sufficient drinking water or water for irrigating crops. The rapid shrinking of No 1 Glacier on Tianshan Mountain in Northwest China's Xinjiang Uygur Autonomous Region is a clear warning of the reality of climate change.

The shrinkage is taking place at the rate of 3.5 meters a year on the eastern part of the glacier and 5.9 meters a year on the western part. The glacier has been in a state of retreat since the 1950s. The continuous shrinking split the glacier into two independent glaciers in 1993. From 1958 to 2004, the average thickness of the glacier decreased by 12 meters and the volume of ice loss reached more than 20 million cubic meters. Long-term observations from 1962 to 2006 showed that the glacier's area decreased by 270,000 square meters at an accelerating rate.

Deserts
Desert expansion has accelerated with each successive decade since 1950. China's Environmental Protection Agency reports that the Gobi Desert expanded by 52,400 square kilometers (20,240 square miles) from 1994 to 1999, an area half the size of Pennsylvania. With the advancing Gobi now within 150 miles of Beijing, China's leaders are beginning to sense the gravity of the situation. The dust bowl currently forming in China is much larger than the one that formed in the Great Plains of the United States during the 1930s when the US population was only 150 million—compared with 1.3 billion in China today.

The increase of dust storms may also lead to severe air pollution episodes, destruction of vegetation, erosion of surfaces, and change in soil pH values, affecting agricultural production, downwind of their source.

Impacts of Climate Change on Human Systems

Climate change has substantially stressed China's economic and social development, especially evident in agriculture and along coastal regions, as well as the energy sector. The increasing frequency and intensity of extreme weather events have brought significant damage to local economies and infrastructure but also attracted national attention to the adverse impacts of climate change.

Agriculture
Agriculture is highly dependent on temperature, precipitation, and water resources, which are greatly affected by climate change. According to CPAACC,[lxiv]

- Climate change has already produced visible adverse effects on China's agriculture and livestock sectors, manifested by increased instability in agricultural production, severe damages to crops and livestock caused by droughts and high temperatures, aggravated spring freeze, and decline in the output and quality of grasslands.
- China expects that the adverse impacts on agriculture and livestock will reduce crop production, such as wheat, paddy rice and corn; change the agricultural production structure; accelerate the decomposition of organic elements in the soil; expand the affected areas suffered from crop diseases and insect pests; degrade grasslands; increase natural fire disasters; reduce livestock production; and increase the risk of livestock epidemics.

Due to the impact of climate change, spring phenophase, a key indicator of crop response to recent regional climate change,[lxv] has advanced two-to-four days since the 1980s.[lxvi] A study conducted by Du et al. (2004) shows observed increases in animal production in Tibet related to the rise of annual temperature, especially during the summer season.[lxvii]

Recent studies[lxviii] show that climate change is likely to significantly influence China's agricultural output. By 2030, overall crop productivity in China could decrease by as much as 5-10 percent if no action is taken. By the second half of the 21st century, climate change could

cause reductions in yields of rice, maize and wheat of up to 37 percent. In the next 20-50 years, agricultural production may be seriously affected, compromising long-term food security in China. The North China Plain is the largest agricultural production area in China. The extensive use of groundwater for irrigation agriculture under variable climatic conditions has resulted in the rapid decline of the groundwater table, especially in areas north of the Yellow River, leading to hydrological imbalance and unsustainable agricultural production. Future climate change is likely to exacerbate the problem.

If the negative impacts of climate change are not effectively controlled, Chinese experts warn that the production of wheat, rice, and corn will be reduced by 37 percent in the late 21st century. From 2010 to 2030, western China would suffer a water shortage of 20 billion cubic meters.[lxix]

Coastal Regions

China's coastal regions consist of eight provinces, two municipalities (Shanghai and Tianjin) and two special administrative regions (Hong Kong and Macao). The regions account for 16.8 percent of China's total land areas, 41.9 percent of its population, and 72.5 percent of China's GDP (including Hong Kong and Macao).[lxx]

With about 144 million square meters, China's low coastal lands, with an elevation less than 5 meters, are the major areas vulnerable to sea level rise and extreme climate events such as storm surges and typhoons. Since the 1960s, these areas have observed increasing frequency and intensity of tropical storms, while the frequency of both the Northwest Pacific tropical cyclones and the related landfall events over China has been decreasing, on average, during the same period.[lxxi]

Energy

According to a recent estimate by the International Energy Agency, China will overtake the United States to become the world's largest energy consumer after 2010.lxxii Energy for the heating and cooling of buildings is expected to grow as a result of improved living standards and hotter summers.

Significantly longer periods of heat waves have been observed in many Chinese cities, especially in eastern and southern China. These two regions are China's most active economic zones, fueled mainly by energy imported from other regions. The frequent heat waves caused a wide use of air conditioning and pushed the local power supply to the edge. The impacted areas suffered power shortages and cutoffs to deal with the shortage.[lxxiii]

Disasters and Hazards

Recent disasters and hazards caused by extreme events have caused significant damage to the local and regional economy, infrastructure, energy transmission, and transportation, as well as the daily life of the affected areas. Nevertheless, extreme weather events—especially floods and storms—have often led to intensive national media coverage, including newspaper, TV and Internet, which have effectively raised public concerns over the adverse impacts of climate change.

A list of major extreme weather events in the past five years includes the following:

- In January and February 2008, 19 provinces in central, eastern, and southern China witnessed unusual snowfall, persistent low temperatures, and icing. The three-week-long extreme weather caused disruptions in transportation and electric power transition, rising food prices,

and damage to agriculture and livestock.[lxxiv,lxxv] At least 100 million people were affected and 60 died.[lxxvi]

- In 2007, Guangdong Province in southern China experienced record rainfall. In Zhanjiang, a coastal province in eastern China, many houses and factories were destroyed by a tornado. In north and west China, the Inner Mongolia Autonomous Region, Shaanxi and Gansu provinces, and Chongqing municipality suffered from record droughts. Some areas of Shaanxi and Chongqing are still experiencing shortages of drinking water.[lxxvii]
- In August 2004, Typhoon Rananim hit the wealthy Zhejiang Province. Rananim killed at least 164 people and 55,000 livestock, injuring more than 1,800 people, destroying 64,300 houses, and affecting 13 million people. The worst typhoon since 1956 resulted in a direct economic loss of $2.2 billion.[lxxviii]

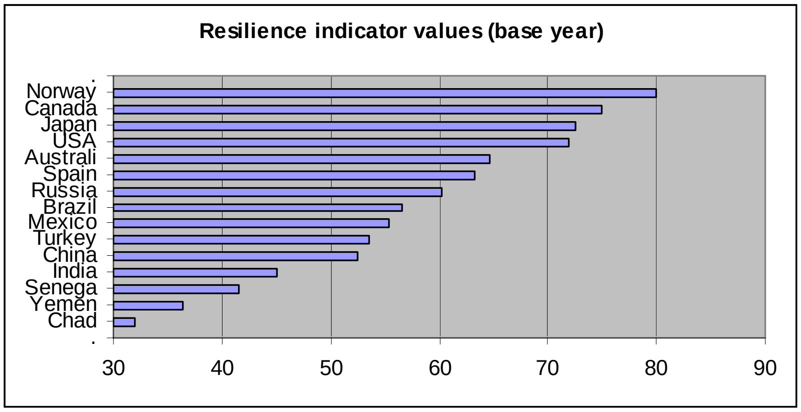
Adaptive Capacity

A global comparative study[lxxix] of resilience to climate change (including adaptive capacity) was conducted using the Vulnerability-Resilience Indicators Model (VRIM—see box below). A sample of 15 countries, including China, spans a wide range of values (Figure 2). A closer look at these countries provides insight into the *sources* of the rankings (see box on page 24).

Methodological Description of the Vulnerability-Resilience Indicator Model (VRIM)

The VRIM is a hierarchical model with four levels. The resilience index (level 1) is derived from two indicators (level 2): sensitivity (how systems could be negatively affected by climate change) and adaptive capacity (the capability of a society to maintain, minimize loss of, or maximize gains in welfare). Sensitivity and adaptive capacity, in turn, are composed of sectors (level 3). For adaptive capacity these sectors are human resources, economic capacity, and environmental capacity. For sensitivity, the sectors are settlement/infrastructure, food security, ecosystems, human health, and water resources. Each of these sectors is made up of 1-3 proxies (level 4). The proxies under adaptive capacity are as follows: human resource proxies are the dependency ratio and literacy rate; economic capacity proxies are GDP (market) per capita and income equity; and environmental capacity proxies are population density, sulfur dioxide divided by state area, and percent of unmanaged land. Proxies in the sensitivity sectors are water availability, fertilizer use per agricultural land area, percent of managed land, life expectancy, birth rate, protein demand, cereal production per agricultural land area, sanitation access, access to safe drinking water, and population at risk from sea level rise.

Each of the hierarchical level values is composed of the geometric means of lower level values. Proxy values are indexed by determining their location within the range of proxy values over all countries or states. The final calculation of resilience is the geometric mean of the adaptive capacity and sensitivity.



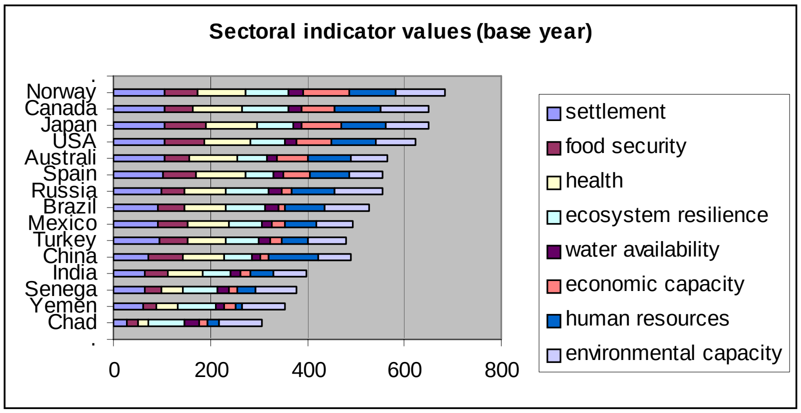


Figure 2. VRIM Base year results: resilience rankings and the element indicator values for example countries.

Impact of Sources on State Vulnerability-Reliance Indicators

- Norway's GDP per capita in combination with the equity index provides the highest resilience ranking among these countries.
- Spain has high scores in economic capacity, settlement security, and food security and human health compared to the other countries, partially offset by the lowest scores in ecosystem resilience and environmental response capacity to climate.
- China scores highest in food security (due to cereal production) and human health and has among the highest scores in human resources.
- Yemen scores lowest in people in the workforce and is low in economic capacity due to inequity. This country also scores low in water availability and cereal production and has a high birth rate.
- Chad scores lowest in settlement security due to lack of access to clean water and sanitation.
- Senegal also scores low in settlement security, but for a different reason: many people live in sea-surge prone areas.

Projections of resilience are based on different rates of change in the proxy values. If the same change rates were used to project the baseline values, countries would travel parallel pathways into the future. A change in ranking can only result from responses that are unique to countries and/or from alternative scenarios. Figure 3 shows projections for the 15-country sample, for the high-growth and delayed-growth scenarios of the future into 2065. The relative rankings of the four lowest-ranked countries do not change in either scenario, although the pathways differ. In the high-growth scenario, countries tend to converge more than in the delayed growth scenario.

The high-growth scenario shows a greater increase in resilience for developing countries than for the developed countries (Figure 4). In the high-growth scenario, China has the largest increase in resilience. It changes ranks from 5th from the bottom among the 15 countries around the turn of the century to "developed country" resilience by 2050. This ranking is equivalent to Spain and even outranks Australia. In the delayed-growth scenario China's resilience increases only a fraction faster than other developing countries, ranking 8th by 2050. Russia also shows potential increase in resilience, especially in the high-growth scenario, by maintaining ecosystem resilience.

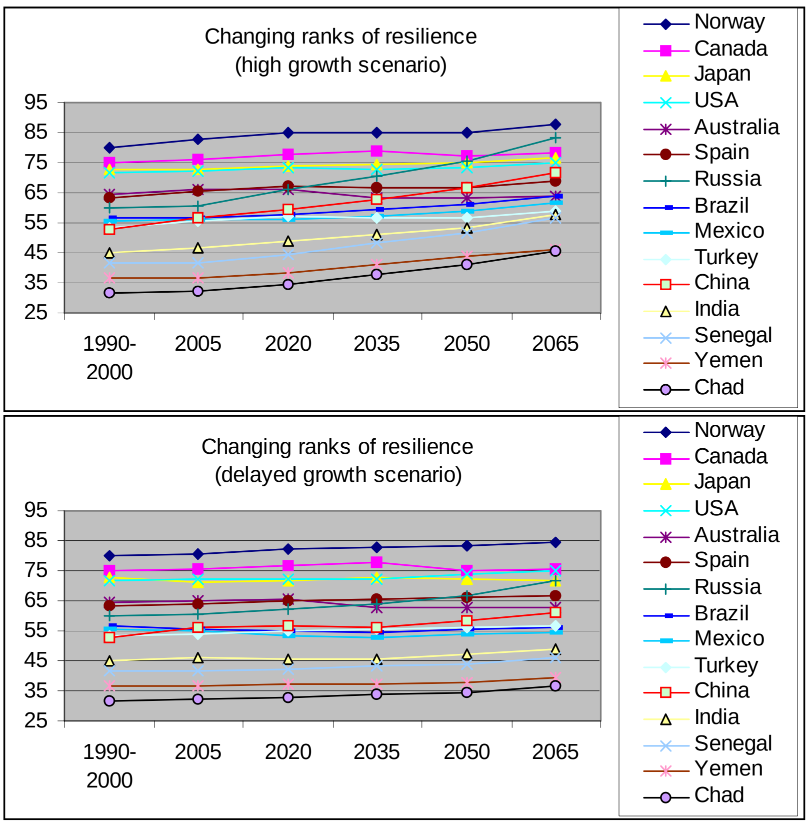


Figure 3. Projections of the resilience indicator value for the example countries.

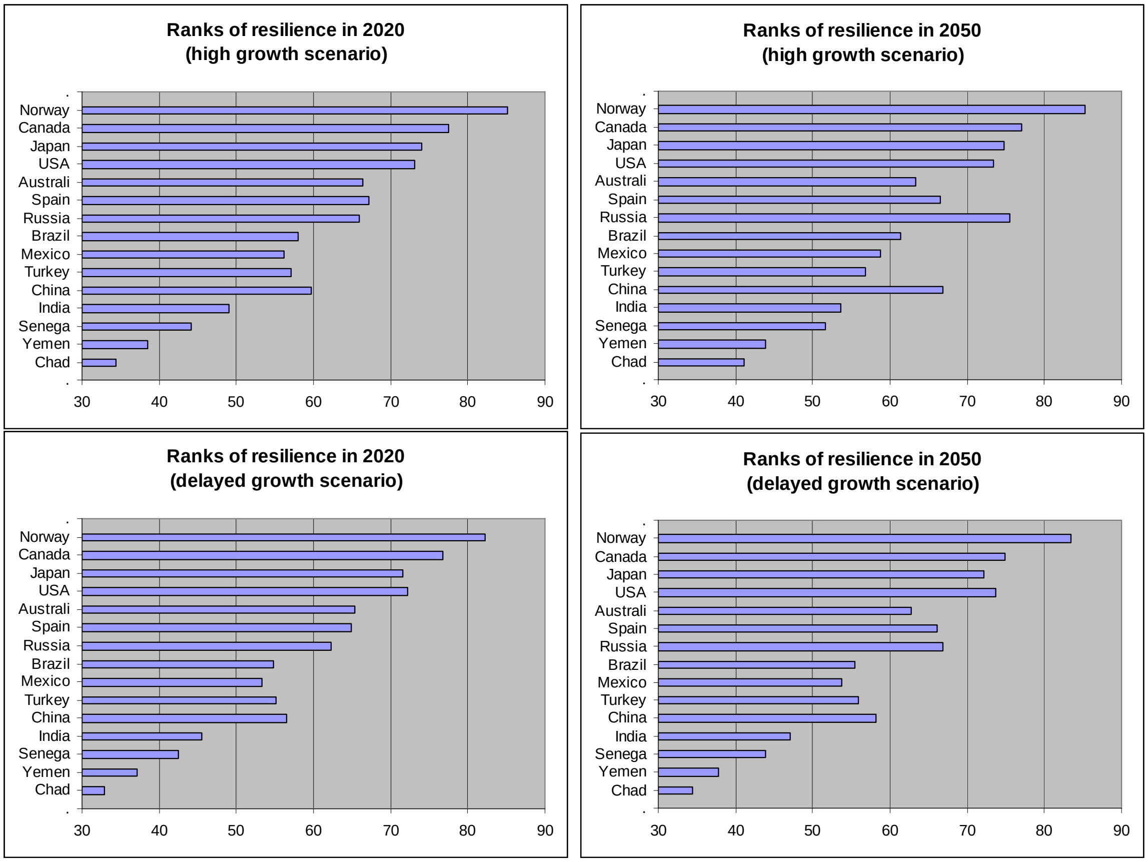


Figure 4. Changes in ranking by 2020 and 2050 for the example countries.

Figure 5 shows the contributing element indicator values to help examine the contributing factors in these phenomena. For example, on the one hand, China's investment in infrastructure alleviates the settlement sensitivity and leads to China becoming considerably more resilient in the high-growth scenario. On the other hand, for the currently highest ranking resilient countries, reduced resilience in ecosystem sensitivity and water availability over time (due to increasing population and land-use changes) is compensated less by economic growth and infrastructure investment than in China.

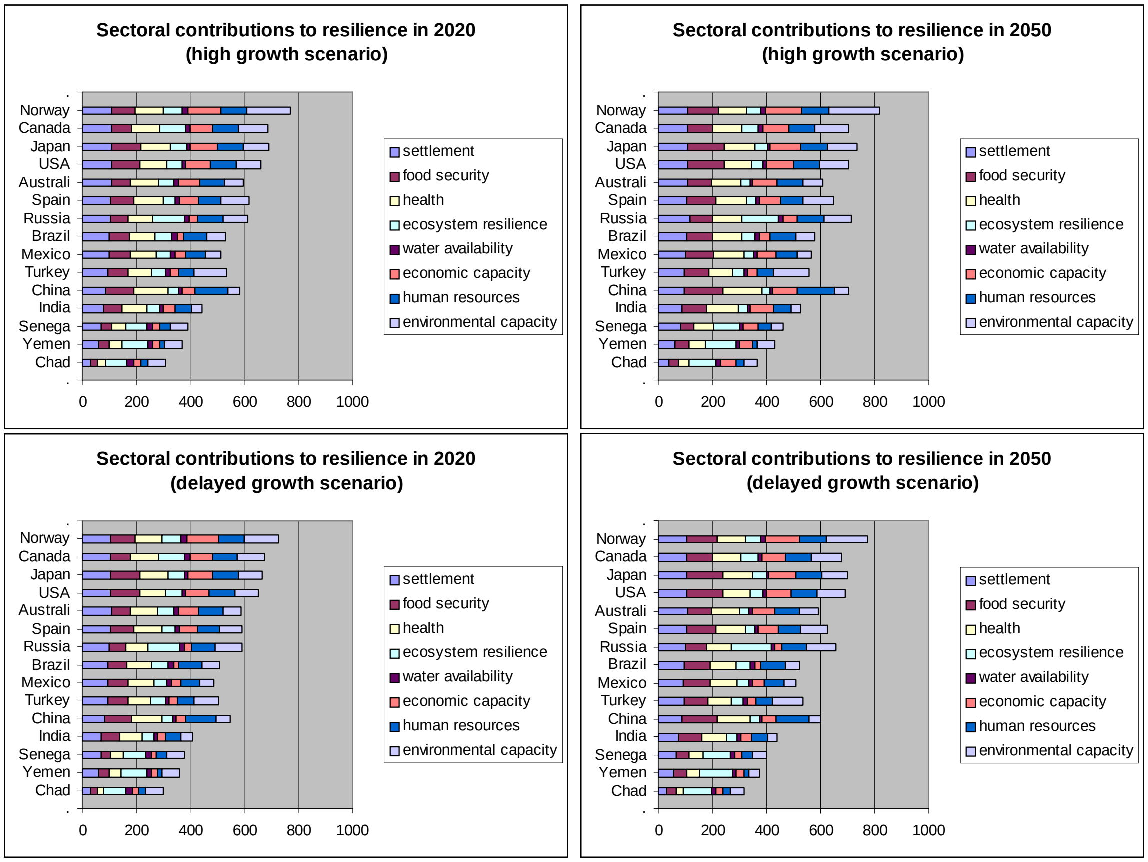


Figure 5. Element indicator values for the example countries.

Current Chinese plans reflect a determination to increase adaptive capacity. The Chinese Government has been promoting mitigation and energy conservation, which had long been regarded as the key strategy for China to battle climate change. With the new stance of “equal emphasis on both mitigation and adaptation,” addressed in *China’s National Climate Change Program* (CNCCP), the government will devote its resources to adaptive capacity-building to buffer the adverse impacts of climate change in China.

According to CNCCP and *China’s Actions and Policies on Climate Change* (CPAACC), China’s past achievements and future actions are reflected in its governmental management of such vulnerable sectors as water, coastal management, agriculture, and forestry. China is also active in building and improving its early warning and monitoring network to reduce avoidable social and economic damages caused by extreme weather events. In addition, the central government has been supporting policy and pouring financial investments into the development of science and technology related to climate change. China continues its national and local public information campaign to raise public awareness and keeps an open and active attitude toward using international available resources for improving its adaptive capacity.

Water Resources

Past Achievements: China has issued a series of laws and regulations to enhance the sustainable use of water resources, including the Law of the Prevention and Control of Water Pollution (1984, 1996), Law of Water and Soil Conservation (1991), Flood Control Law (1997), and Water Law (2002). China also set up programs of flood control and disaster alleviation for major

rivers, as well as water conservation programs. By the end of 2007, China has successfully controlled soil erosion over one million square kilometers.[lxxx]

Future Actions: According to the CNCCP and the CPAACC, China will take the following strategies to enhance adaptive capacity of water resources to climate change:[lxxxi]

(1) China will establish a national system of water right allocation and water right transfer and develop market-oriented financing and a management system for key water conservation projects.

(2) China will construct projects to control floods on major rivers and floods caused by mountain torrents. To alleviate the trend of droughts in the north and floods in the south, China plans to speed the construction of the Project of South-to-North Water Diversion, which aims to help optimize the allocation of water resources from the Yangtze River, Yellow River, Huaihe River, and Haihe River. In addition, China will continue the construction of regional water storage and water diversion projects.

(3) China will promote technology development for water conservation, sea water use, wastewater and rainfall utilization, artificial rainfall enhancement, industrial water recycling, and water efficiency irrigation, etc.

China's near-term goals by 2010 are to complete anti-flood systems in major rivers, raise the drought relief standard in farmland, and effectively reduce the vulnerability of water resources to climate change.[lxxxii]

Coastal Management

Past Achievements: China's coastal regions are the country's most economically developed regions. Since the 1980s, China has launched a series of laws to protect coastal regions and marine resources, such as the Marine Environment Protection Law (1983 and 1999), China's Marine Programs (1998), and Law of Administration of Sea Areas (2002).[lxxxiii]

Future Actions: Due to their low and flat landscape, the lack of monitoring and emergency response network, as well as less stringent standards of anti-tide construction, China's coastal regions are vulnerable to sea level rise, coastal erosion, and soil salinization. According to the CNCCP and CPAACC,[lxxxiv] China will take the following strategies to improve the adaptive capacity of its coastal areas:

(1) China will build up regional management regulations in accordance with the related laws, establish an integrated coastal zone management system and coordination mechanism, develop demonstration sites for integrated management, and improve design standards for sea dike and port docks. China will also speed up the process of setting up natural reserves for coral reefs and mangroves.

(2) China will invest R&D focused on protection and restoration of marine ecosystems, including the cultivation, transplant, and recovery of coastal mangroves, protection and restoration of coral reefs, as well as the protection of coastal wetlands and ecosystems.

(3) China will build more observation sites in coastal areas and on islands, improve the capability of aerial remote sensing and telemetering of marine environments, and build early-warning and response systems for tidal disasters.

China's near-term goals are to construct and expand mangroves, to effectively raise the adaptive capacity of coastal regions by establishing a monitoring network and related regulations, and to construct a coastal shelterbelt system by 2010.[lxxxv]

Agriculture

Past Achievements: Agriculture is one of the most important economic sectors in China, employing over 300 million laborers[lxxxvi] (the largest labor-intensive sector) and contributing to 11.3 percent of GDP in 2007 (the third largest, after the industry and service sectors).[lxxxvii] China has issued a series of laws and regulations related to agriculture, such as the Grassland Law (1985), Fisheries Law (1986), Law on Land Management (1986, 1998), Regulations of Responses to Major Emergent Animal Epidemics, Agriculture Law (2002), and Livestock Epidemics (2003). The government has invested heavily in agricultural infrastructure, improved irrigation and drainage efficiency and capability, and promoted dry farming and water-efficient technologies. China also has been actively promoting the cultivation of stress-resistant crop seeds.[lxxxviii]

Future Actions: According to the CNCCP, China's strategies for improving adaptive capacity of the agricultural sector can be summarized as follows:[lxxxix]

(1) China will promote production clusters using advantageous crop varieties. The government will continue to expand the demonstration projects on water efficiency irrigation and on dryland farming in arid areas. China will protect and improve the grassland ecosystem by converting grazing areas back to grassland; constructing meadow enclosures, artificial grasslands and grassland fire-prevention facilities; and carrying out projects to protect aquatic ecosystems.

(2) China will accelerate the construction of supporting facilities for large-scale, water-saving irrigation areas; upgrade aging mechanical and electronic equipment; improve irrigation and drainage systems; and conduct small-scale hydraulic projects focused on field irrigation and drainage. China will accelerate the construction of water collection and utilization projects in mountain areas and other arid areas.

(3) China will develop varieties of crops and livestock resistant to drought, waterlogging, high temperature, diseases, and pests. Technology development will be focused on photosynthesis, biological nitrogen fixation, bio-technology, prevention of diseases and pests, stress resistance, and precision agriculture.

By 2010, China's near-term goals are to increase improved grassland by 24 million hectares, restore 52 million hectares of grassland affected by degradation, desertification, and salinity, and strive to increase the efficient utilization agricultural irrigation water.[xc]

Forestry

Past Achievements: To protect forest and other ecosystems, China has issued and enforced relevant laws and regulations, including the Forest Law (1984, 1998), Law on the Protection of Wildlife, Law on Water and Soil Conservation (1989), Management Regulations on National Forest Diseases and Insect Pests Central Monitoring Stations (2001), Law on Prevention and Control of Desertification (2002), Regulations on Conversion of Farmland to Forests, and Forest Fire Prevention Regulations (2003).[xci] The government has established a comprehensive monitoring system for forest resources and ecosystem conditions; improved an evaluation system and emergency-response system for forest fires, pests and diseases; implemented a national

medium- and long-term program for the prevention of forest fires, pests and diseases; enhanced the protection of endangered species and their habitat ecosystems; and restored the functions of eco-fragile areas and ecosystems.

Future Actions: According to the CNCCP, China's strategies to improve adaptive capacity for the forestry sector can be summarized as follows:[xcii]

(1) China will amend the Forest Law and Law on the Protection of Wildlife, draft a Law of Nature Reserve and Regulations on Wetland Protection, and address climate change adaptation in existing laws by adding new articles or contents.

(2) The government will strengthen the protection of existing forest resources and other natural ecosystems, restore degraded natural forest ecosystems progressively, protect wetland conservation, expand the total area of nature reserves, and develop bio-corridors among reserves. China also will strengthen controls on forest fire, insect and disease, and integrate existing forestry monitoring systems into a comprehensive monitoring system for forest resources and other ecosystems.

(3) The focus areas include forest fire control; forest insect and disease control; and development of tree species with a high resistance to cold, drought, pests, and disease. China also will focus on biodiversity conservation and restoration; and monitoring technologies for forest resources and forest ecosystems, such as desertification, wild animals and plants, wetlands, forest fires, forest pests and diseases.

By 2010, China's near-term goals are to increase the forest coverage rate to 20 percent and to increase the carbon sink by 50 million tons over 2005's level. China also will aim to protect 90 percent of forest ecosystems and national key wildlife, increase nature reserve areas to 16 percent of the total territory, and control 22 million hectares of desertificated lands during the same time.[xciii]

Early Warning System and Monitoring Network

In the face of increasing extreme meteorological emergencies, China has improved its early warning system and monitoring network to enhance adaptive capacity in vulnerable sectors such as coastal management, agriculture, and forestry.

In early 2009, the China Meteorological Administration issued a circular urging its branches at all levels to provide accurate extreme weather forecasts (such as for snow, frost, rain, and storms) to "local governments, relevant organizations and the public via phone, text messages, e-mail and other methods." The circular especially stressed that the grain production bases located in north China and Yellow River and Huai Rivers should be provided with updated drought information.[xciv]

To counter flood and storms, local governments have been required to develop city flood control and water drainage plans. The state will further establish its monitoring and control network to deal with epidemic-infected area caused by climate change.[xcv]

The People's Liberation Army (PLA) has often been deployed by the government as an emergency rescue team to the affected areas when facing extreme weather events like floods and storms. PLA, called the People's Army, has been highly praised for self-sacrifice and efficiency.

Raising Public Awareness

Past Achievements: With the purpose of fostering a social atmosphere to build a resources-conserving and environmentally friendly society, China has been conducting intensive social marketing to raise public awareness on energy conservation and climate change. Since 1992, China has launched 18 National Energy Conservation Weeks. The government issued the Public Action Plan on Energy Conservation and Emission Reduction, and coordinated relevant national and local activities with communities, enterprises, schools, governmental agencies, and the mass media. The Chinese Government requires governmental agencies to take leadership to reduce their own energy consumption in building and transportation. China also encourages citizens to change their lifestyles and consumption patterns for energy conservation and emission reduction. In recent years, nongovernmental organizations and many social groups have been actively playing a role in promoting energy conservation and emission reduction.[xcvi]

Future Actions: According to the CNCCP, China's strategies to raise public awareness can be summarized as follows:[xcvii]

(1) All level of governmental officials and decision-makers of enterprises and institutions should be exposed to climate change information and work toward raising public awareness.

(2) China will fully employ the power of the mass media to disseminate information about climate change through books, newspapers, periodicals, audio and video products, and the Internet. China will integrate knowledge about climate change into its education system.

(3) China will establish an incentive mechanism to encourage public and enterprise participation, increase the transparency of decision-making processes related to climate change issues, promote public supervision, and encourage social groups and NGOs to play active roles.

(4) China will strengthen international cooperation on public awareness related to climate change issues, especially good practices on climate change information dissemination and education. China will actively promote information exchanges in the form of publications, movies, television, audio and video tapes and other literature, building a database on climate change and providing information retrieval services for domestic agencies, research institutions, and schools.

By 2010, China's near-term goals are to raise awareness of all Chinese society on climate change and to establish a high-efficient institutional and management framework to address climate change.[xcviii]

Enhancing R&D Investment

Past Achievements: In 2006, China invested $38.5 billion on R&D, 1.4 percent of its GDP that year, up 22 percent from 2005. The government also announced 16 national key projects and 10 national laboratories to be completed by 2020.[xcix] In 2007, the Chinese Government earmarked $556 million (20 percent higher than in 2006) for the National Natural Science Foundation, an organization similar to the US National Science Foundation.[c] Energy and environment are two important R&D areas attracting government funding.

Future Actions: According to the CNCCP, China's strategies to enhance climate change-related R&D are summarized as follows:[ci]

(1) China will support climate change-related R&D under the framework of the National Program for Medium-to-Long-Term Scientific and Technological Development (2006-2020), strengthen the macro management and policy guidance for scientific and technological research related to climate change, improve regional and sectoral research, and encourage innovation of climate change science and technology.

(2) China will promote scientific research and technological development in the following key areas: scientific facts and uncertainty, impacts of climate change on the social economy, analysis of the effectiveness of socioeconomic benefits and costs in response to climate change, and technology for mitigation and adaptation. China will pay special attention to the development of large-scale and precise climate change monitoring technology, energy efficiency and clean energy technology, emission control and utilization technology for carbon dioxide, methane and other greenhouse gas emissions in key sectors, biological carbon-capture technology, and carbon sequestration technology.

(3) China will establish effective incentive and competition mechanisms and a favorable academic environment for researchers, foster academic leaders and eminent candidates with international vision and the ability to lead climate change studies, and encourage junior research. China will strengthen the disciplinary development of climate change science, promote research teams, establish the “open, free, competitive, and cooperative” operation mechanism for climate change research institutes, and make full use of various channels and approaches to enhance the research ability and independent-innovation capacity of China’s scientists and research institutions. China will build up climate change science and technology management teams and R&D teams in the context of China’s national circumstances, encouraging Chinese scientists to participate in international R&D programs on global climate change and pursue positions in international research institutions.

(4) China will establish relatively stable governmental-funded channels as the main financing sources to support climate change-related scientific and technological research, taking measures to ensure the full allocation and efficient use of governmental investment; raise funds through various channels and by various means from all sectors of the society; introduce venture capital investment in the area of climate change research; guide business and enterprises to increase their investment in R&D on climate change science and technology and encourage them to take a leading role for technology innovation; and use the bilateral and multilateral funds from foreign governments and international organizations to assist China’s R&D on climate change science and technology.

Using International Resources

Since the late 1980s, China has been actively using international resources, such as foreign governments, international organizations and research institutes, to promote its science and technology development related to energy efficiency and climate change.

The international collaboration not only improves China’s research capacity but also influences China’s climate-related policies, such as policies adopted by China’s farming and forestry departments, China’s water resources management, China’s comprehensive management of coastal zone and marine ecosystems, and China’s laws and regulations related to climate change. In addition, China enhances information exchanges and resource sharing with international organizations and institutes.[cii]

For bilateral exchanges related to climate change issues, China has established a dialogue and cooperation mechanism with the European Union, Japan, the United States, Canada, the United Kingdom, Australia, India, Brazil, and South Africa.

China actively participates in international scientific and technological cooperation programs, including the Intergovernmental Panel on Climate Change, the World Climate Research Programme under the framework of the Earth System Science Partnership, the International Geosphere-Biosphere Programme, the International Human Dimensions Programme on Global Environmental Change, the Intergovernmental Group on Earth Observations, the Global Climate Observation System, the Global Ocean Observation System, the Array for Real-Time Geostrophic Oceanography, and the International Polar Year.

Through international cooperation, China has conducted systematic research under the clean development mechanism (CDM). By July 2008, China had implemented 244 CDM cooperation projects, which were registered with the United Nations. It is expected that the reduction of carbon dioxide emissions through CDM projects will reach 113 million tons per year.[ciii]

Conclusions: High-Risk Impacts

China has demonstrated its determination to tackle the climate change issues as an important domestic affair. However, the government has not seriously addressed some prominent climate impact issues, such as the underrated and underpublicized water crisis, the climate security of coastal regions, and the underdeveloped social protection system. In addition, China must demonstrate an ability to implement its ambitious plans.

Water

With 20 percent of the world's population but only 7 percent of global water resources, China is suffering an underrated water crisis. According to Chinese studies, China's water supply is likely to reach its limit by 2030 when its population hits 1.6 billion with an urbanization rate of 60 percent. China's water supply will fall 11 billion cubic meters annually in spite of the improved supply capacity.[civ] Beijing is among the most affected cities.

A scarcity of natural water resources, fast-growing urbanization and industrialization, severe water pollution, and cheap water prices are among the main factors leading to China's water crisis. The adverse impacts of climate change on water sources, especially with frequent droughts in the north, will push the crisis even further.

The drought regions may be prone to social unrest caused by water shortages. Conflicts over water rights and distribution between social groups and between sectors may occur. The serious middle- and long-term droughts may lead environmental refugees to flee to water-rich regions. The expected South-to-North Water Diversion Project may alleviate the water stress of some northern regions, but it will not be sufficient enough to provide a full solution.[cv]

Frequent and prolonged droughts and floods will not only affect livelihoods, but also damage the local, regional, and national economy. With 300 million workers, agriculture, which is highly water-dependent, may be at greater risk than all other sectors. The negative impacts on agriculture will bring high risk for China's food security but also lead to an influx of immigrants to urban areas for jobs, transferring resource and social stress to Chinese cities.

Coastal Regions
China has an 18,000-km coastline, and one third of China's border faces the sea. With 16.8 percent of China's total land area, 41.9 percent of the population, and 72.5 percent of China's GDP, the coastal regions are the engine of China's sustainable economic growth.

However, due to their flat and low landscape, most of China's coastal regions are highly vulnerable to sea level rise, including Shanghai—China's business and financial hub. The increasing frequency and intensity of extreme weather events such as typhoons has threatened the economic development at local, regional, and national levels.

China has been actively developing early warning systems and related monitoring systems and improving the design standards of sea dike and port docks. Improved management, including increased effectiveness of early-warning and monitoring systems, better enforcement of design standards, and increase in trained emergency responses teams could lower the risk of damage from extreme weather events.

Social and Political Uncertainties
China's actual unemployment rate in the past three years is widely believed to be much higher than the official 9.6 percent.[cvi] Facing a large unemployed population, China's underdeveloped social protection system is less and less able to protect those who need it. Rising expenses on healthcare, education and housing have been financial burdens for the average Chinese family. The export-oriented economy is vulnerable to the present global financial crisis. Chinese experts believe that 2009 will be a difficult year for China's economy.[cvii] As the second largest oil importer, China has exposed itself to an unstable international oil market.

The adverse impacts of climate change will add extra pressure to the existing social and resource (such as energy) stresses. Establishing an effective social protection system will be ranked high in the Chinese Government's long to-do list.

Policy Implementation
There is little doubt that China has taken climate change issues seriously, although China's seriousness has often been overlooked due to its more-publicized, non-negotiable, "you-take-the-first-step" attitudes in international negotiations. Evidence of China's seriousness is apparent in its fast growing array of national laws, regulations, and policies that focus on mitigation, energy efficiency, resource protections, and adaptive capacities. The Chinese Government has successfully used its power to promote and implement some of its national programs and policies, such as energy efficiency standards for appliances, top 1,000 industrial energy conservation program,[cviii] and an efficient light bulb subsidy program.[cix]

In the context of a mixed economy, conflicted interests and different priorities between national and local governments, and complicated stakeholder relations, implementation is China's big hurdle for the success of mitigation and adaptation. For example, compliance with the building energy code is mandated under Chinese law. However, the actual enforcement rate is very low in mid- and small-sized cities.[cx] Building adaptive capacities will face the same challenge. Smart employment of a set of policy instruments, such as regulations, incentive and voluntary programs, and well-designed local action plans could improve implementation. Other countries could help China by sharing their experiences on implementation.

Annex A: Accuracy of Regional Models

This is an excerpt from IPCC (2007), Chapter 11, Regional models; see IPCC 2007 for references. [4]

11.4.2 Skill of Models in Simulating Present Climate

Regional mean temperature and precipitation in the MMD models show biases when compared with observed climate (Table 3). The multi-model mean shows a cold and wet bias in all regions and in most seasons, and the bias of the annual average temperature ranges from –2.5°C over the Tibetan Plateau (TIB) to –1.4°C over South Asia (SAS). For most regions, there is a 6°C to 7°C range in the biases from individual models with a reduced bias range in Southeast Asia (SEA) of 3.6°C. The median bias in precipitation is small (less than 10 percent) in Southeast Asia, South Asia, and Central Asia (CAS), larger in northern Asia and East Asia (NAS and EAS, around +23 percent), and very large in the Tibetan Plateau (+110 percent). Annual biases in individual models are in the range of –50 to +60 percent across all regions except the Tibetan Plateau, where some models simulate annual precipitation 2.5 times that observed and even larger seasonal biases occur in winter and spring. These global models clearly have significant problems over Tibet, due to the difficulty in simulating the effects of the dramatic topographic relief, as well as the distorted albedo feedbacks due to extensive snow cover. However, with only limited observations available, predominantly in valleys, large errors in temperature and significant underestimates of precipitation are likely.

South Asia

Over South Asia, the summer is dominated by the southwest monsoon, which spans the four months from June to September and dominates the seasonal cycles of the climatic parameters. While most models simulate the general migration of seasonal tropical rain, the observed maximum rainfall during the monsoon season along the west coast of India, the north Bay of Bengal and adjoining northeast India is poorly simulated by many models (Lal and Harasawa, 2001; Rupa Kumar and Ashrit, 2001; Rupa Kumar et al., 2002, 2003). This is likely linked to the coarse resolution of the models, as the heavy rainfall over these regions is generally associated with the steep physical geography of local mountains. However, the simulated annual cycles in South Asian mean precipitation and surface air temperature are reasonably close to the observed. The multi-model data set (MMD) models capture the general regional features of the monsoon, such as the low rainfall amounts coupled with high variability over northwest India. However, there has not yet been sufficient analysis of whether finer details of regional significance are simulated more adequately in the MMD models.

Recent work indicates that time-frame experiments using an atmospheric general circulation model (AGCM) with prescribed sea surface temperatures (SSTs), as opposed to a fully coupled system, are not able to accurately capture the South Asian monsoon response (Douville, 2005). Thus, neglecting the short-term SST feedback and variability seems to have a significant impact on the projected monsoon response to global warming, complicating the regional downscaling problem. However, May (2004a) notes that the high-resolution (about 1.5 degrees) European Centre-Hamburg (ECHAM4) general circulation model (GCM) simulates the variability and extremes of daily rainfall (intensity as well as frequency of wet days) in good agreement with the observations (Global Precipitation Climatology Project, Huffman et al., 2001).

[4] Some references in this section have been changed to be internally consistent with this document and other references have been removed to avoid confusion.

Three-member ensembles of baseline simulations (1961–1990) from a regional climate model (RCM) (PRECIS) at 50 km resolution have confirmed that significant improvements in the representation of regional processes over South Asia can be achieved (Rupa Kumar et al., 2006). For example, the steep gradients in monsoon precipitation with a maximum along the western coast of India are well represented in PRECIS.

East Asia

Simulated temperatures in most MMD models are too low in all seasons over East Asia; the mean cold bias is largest in winter and smallest in summer. Zhou and Yu (2006) show that over China, the models perform reasonably well in simulating the dominant variations of the mean temperature over China, but not the spatial distributions. The annual precipitation over East Asia exceeds the observed estimates in almost all models and the rain band in the mid-latitudes is shifted northward in seasons other than summer. This bias in the placement of the rains in central China also occurred in earlier models (e.g., Zhou and Li, 2002; Gao et al., 2004). In winter, the area-mean precipitation is overestimated by more than 50 percent on average due to strengthening of the rain band associated with extratropical systems over South China. The bias and inter-model differences in precipitation are smallest in summer but the northward shift of this rain band results in large discrepancies in summer rainfall distribution over Korea, Japan and adjacent seas.

Kusunoki et al. (2006) find that the simulation of the Meiyu-Changma-Baiu rains in the East Asian monsoon is improved substantially with increasing horizontal resolution. Confirming the importance of resolution, regional climate models (RCMs) simulate more realistic climatic characteristics over East Asia than atmospheric-ocean general circulation models (AOGCMs), whether driven by re-analyses or by AOGCMs (e.g., Ding et al., 2003; Oh et al., 2004; Fu et al., 2005; Zhang et al., 2005a, Ding et al., 2006; Sasaki et al., 2006b). Several studies reproduce the fine-scale climatology of small areas using a multiply nested RCM (Im et al., 2006) and a very-high resolution (5 km) RCM (Yasunaga et al., 2006). Gao et al. (2006b) report that simulated East Asia large-scale precipitation patterns are significantly affected by resolution, particularly during the mid- to late-monsoon months, when smaller-scale convective processes dominate.

Southeast Asia

The broad-scale spatial distribution of temperature and precipitation in December-January-February (DJF) and June-July-August (JJA) averaged across the MMD models compares well with observations. Rajendran et al. (2004) examine the simulation of current climate in the MRI coupled model. Large-scale features were well simulated, but errors in the timing of peak rainfall over Indochina were considered a major shortcoming. Collier et al. (2004) assess the performance of the CCSM3 model in simulating tropical precipitation forced by observed SST. Simulation was good over the maritime continent compared to the simulation for other tropical regions. Wang et al. (2004) assess the ability of 11 AGCMs in the Asian-Australian monsoon region simulation forced with observed SST variations. They found that the models' ability to simulate observed interannual rainfall variations was poorest in the Southeast Asian portion of the domain. Since current AOGCMs continue to have some significant shortcomings in representing El Niño- Southern Oscillation (ENSO) variability, the difficulty of projecting changes in ENSO-related rainfall in this region is compounded.

Rainfall simulation across the region at finer scales has been examined in some studies. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) stretched-grid Conformal-Cubic Atmospheric Model (CCAM) at 80-km resolution shows reasonable

precipitation simulation in JJA, although Indochina tended to be drier than in the observations (McGregor and Nguyen, 2003). Aldrian et al. (2004a) conducted a number of simulations with the Max-Planck Institute (MPI) regional model for an Indonesian domain, forced by reanalyses and by the ECHAM4 GCM. The model was able to represent the spatial pattern of seasonal rainfall. It was found that a resolution of at least 50 km was required to simulate rainfall seasonality correctly over Sulawesi. The formulation of a coupled regional model improves regional rainfall simulation over the oceans (Aldrian et al., 2004b). Arakawa and Kitoh (2005) demonstrate an accurate simulation of the diurnal cycle of rainfall over Indonesia with an AGCM of 20-km horizontal resolution.

Central Asia and Tibet

Due to the complex topography and the associated mesoscale weather systems of the high-altitude and arid areas, GCMs typically perform poorly over the region. Importantly, the GCMs, and to a lesser extent RCMs, tend to overestimate the precipitation over arid and semi-arid areas in the north (e.g., Small et al., 1999; Gao et al., 2001; Elguindi and Giorgi, 2006).

Over Tibet, the few available RCM simulations generally exhibit improved performance in the simulation of present-day climate compared to GCMs (e.g., Gao et al., 2003a,b; Zhang et al., 2005b). For example, the GCM simulation of Gao et al. (2003a) overestimated the precipitation over the north-western Tibetan Plateau by a factor of five to six, while in an RCM nested in this model, the overestimate was less than a factor of two.

		temperature BIAS					% precipitation BIAS				
REGION	SEASON	MIN	25	50	75	MAX	MIN	25	50	75	MAX
Asia											
NAS	DJF	-9.3	-2.9	-1.3	0.0	2.9	-18	5	12	19	93
	MAM	-6.0	-4.3	-2.7	-0.5	0.6	-4	39	45	74	110
	JJA	-4.8	-2.0	-0.5	0.4	2.2	-38	-2	19	32	62
	SON	-6.2	-2.6	-2.1	-0.5	1.9	-14	12	23	30	49
	ANN	-5.2	-2.6	-1.4	-0.6	1.3	-11	15	24	35	55
CAS	DJF	-4.4	-2.6	-1.2	0.2	3.3	-33	-2	18	43	77
	MAM	-4.3	-3.0	-1.4	0.2	2.0	-36	22	25	34	83
	JJA	-4.9	-1.6	0.3	1.4	5.7	-71	-37	-25	14	60
	SON	-4.5	-3.2	-1.9	-0.4	1.6	49	-12	-4	15	47
	ANN	-3.9	-2.3	-1.4	0.6	2.2	-44	4	12	21	53
TIB	DJF	-9.3	-3.8	-2.2	-1.4	2.2	15	131	177	255	685
	MAM	-7.0	-4.3	-3.8	-1.3	0.6	130	160	209	261	486
	JJA	-6.7	-2.5	-1.0	-0.2	1.6	4	30	37	53	148
	SON	-5.9	-3.6	-2.5	-1.7	0.0	66	93	150	180	330
	ANN	-5.3	-3.3	-2.5	-1.6	0.6	51	88	110	142	244
EAS	DJF	-6.5	-4.5	-3.7	-1.3	1.8	-20	26	60	79	142
	MAM	-5.2	-2.9	-2.0	-1.0	0.5	1	32	45	60	105
	JJA	-3.9	-2.0	-1.1	-0.4	1.4	-15	0	3	15	27
	SON	-5.9	-3.4	-2.7	-1.6	-0.3	-17	1	14	34	75
	ANN	-5.4	-3.2	-2.5	-1.2	0.2	-6	12	22	31	60
SAS	DJF	-7.4	-4.0	-2.6	-1.6	1.9	-27	0	30	59	127
	MAM	-5.6	-1.9	-0.7	-0.4	2.5	-44	-26	-1	13	72
	JJA	-2.9	-1.3	-0.1	0.6	1.9	-70	-25	-14	5	29
	SON	-5.2	-3.2	-2.1	-0.9	2.6	-26	-12	-2	14	42
	ANN	-4.8	-2.4	-1.4	-0.8	2.2	-49	-16	-10	5	33
SEA	DJF	-3.6	-2.6	-1.8	-1.2	0.4	-37	-10	-2	26	49
	MAM	-2.6	-1.6	-0.5	-0.1	1.1	-32	-9	11	25	59
	JJA	-2.5	-1.8	-0.7	-0.4	1.0	-28	-10	4	16	46
	SON	-3.0	-1.9	-1.2	-0.8	1.0	-37	-12	-4	18	51
	ANN	-2.8	-1.9	-1.0	-0.5	0.8	-28	-13	0	23	43

Table 3. Biases in present-day (1980-1999) surface air temperature and precipitation in the MMD simulations. The simulated temperatures are compared with the HadCRUT2v (Jones, et al., 2001) data set and precipitation with the CMAP (update of Xie and Arkin, 1997) data set. Temperature biases are in °C and precipitation biases in per cent. Shown are the minimum, median (50 percent) and maximum biases among the models, as well as the first (25 percent) and third (75 percent) quartile values. Colors indicate regions/seasons for which at least 75 percent of the models have the same sign of bias, with orange indicating positive and light violet negative temperature biases and light blue positive and light brown negative precipitation biases.

Annex B: Knowledge Deficiencies that Preclude a Full Evaluation of Climate Change Impacts on China and China's Adaptive Strategies

To increase the likelihood that this evaluation represents a reasonable assessment of China's projected climate changes and their impacts, as well as the country's adaptive capacity, the following gaps would need to be addressed:

- In physical science research, regional analyses will continue to be limited by the inability to model regional climates satisfactorily, including complexities arising from the interaction of global, regional, and local processes. Uncertainties in changing monsoonal activity, dust storms, and desertification leave important gaps in knowledge needed for climate projections. One gap of particular interest is the lack of medium-term (20-30 years) projections that could be relied upon for planning purposes. Similarly, scientific projections of water supply and agricultural productivity are limited by inadequate understanding of various climate and physical factors affecting both areas. Research agendas in these areas can be found in, for instance, the synthesis and assessment reports of the US Climate Change Science Program (http://www.climatescience.gov) and the National Academy of Sciences (e.g., http://books.nap.edu/catalog.php?record_id=11175#toc). Similar types of issues exist for the biological and ecological systems that are affected.
- In social science research, scientists and analysts have only partial understandings of the important factors in vulnerability, resilience, and adaptive capacity—much less their interactions and evolution. Again, research agendas on vulnerability, adaptation, and decision-making abound (e.g., (http://books.nap. edu/catalog.php?record_id=12545).
- Important factors are unaccounted for in research; scientists know what some of them are, but there are likely factors whose influence will be surprising. An example from earlier research on the carbon cycle illustrates this situation. The first carbon cycle models did not include carbon exchanges involving the terrestrial domain. Modelers assumed that the exchange was about equal, and the only factor modeled was deforestation. This assumption, of course, made the models inadequate for their purposes. In another example, ecosystems research models are only beginning to account for changes in pests, e.g., the pine bark beetle.
- Social models or parts of models in climate research have been developed to simulate consumption (with the assumption of well-functioning markets and rational actor behavior) and mitigation/adaptation policies (but without attention to the social feasibility of enacting or implementing such policies). As anthropogenic climate change is the result of human decisions, the lack of knowledge about motivation, intent, and behavior is a serious shortcoming.

Overall, research about climate change impacts on China has been undertaken piecemeal: discipline by discipline, sector by sector, with political implications separately considered from physical effects. This knowledge gap can be remedied by integrated research into energy-economic-environmental-political conditions and possibilities.

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SPECIAL REPORT

INDIA: IMPACT OF CLIMATE CHANGE TO 2030
A COMMISSIONED RESEARCH REPORT